Technology Progress, Efficiency, and Scale of Economy in Post-reform China

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ABSTRACT

This paper analyzes the productivity change of the thirty provinces in China's post-reform economy. The productivity change is estimated from the stochastic frontier model, in which the maximum likelihood estimation is applied to an augmented logarithmic production function incorporated with a human capital variable. The empirical results show technical progress is the main contributor to productivity growth and the scale of economy became important in recent years, but technical efficiency has edged downwards in the sample period. We also found that the physical capital is the important factor for economic growth and human capital is inadequate even though it has a positive and significant effect on growth. The relevant policy implication for a sustainable post-reform China economy is the need to promote human capital accumulation and improvement in technical efficiency.

Key Words: technical efficiency, technical progress, human capital, China economy

JEL Classification: C2, D24, O4, O53

1. Introduction

There are numerous studies on the post-reform performance of the China economy. Recent studies include regional differences (Yao and Zhang 2001; Cai *et al* 2002 and Yang 2002) and the focus on growth with civic development and system change (Young 2000 and 2003). One line of analysis on the post-reform China economy begins with the study on financial resources. For example, Li (1992; 1994 and 1997a) and Li and Leung (1994) have considered the relationship between various financial and monetary variables on the post-reform China economy, providing analysis as to whether financial and monetary variables contributed to productivity and growth.

The study of financial and monetary variables is then extended to consider the different forms of financial resources within the framework of financial liberalization in the banking and finance sector. Li and Liu (2001 and 2004) and Liu and Li (2001), for example, have analyzed the impact of financial liberalization on China's national and provincial growth, while Li (1997b and 1999) and Li and Ma (2004) have examined China's banking reform and liberalization. The more recent wave of study has deepened the liberalization concept and instead used investment data to examine productivity and growth. Chow and Li (2002) and Li (2003) constructed the national and provincial capital stock using different investment sources to work out the total factor productivity (TFP), while Liu and Li (2006) and Li (2007) further extended the analysis on TFP to incorporate the human capital variable and provincial performance. Although different approaches have been used, the empirical work on TFP, human capital and economic growth in the post-reform China economy has been supported by many studies (Borensztein and Ostry 1996; Lin 2000; Wang and Yao 2003 and Fleisher *et al* 2005).

The reliability of China's macroeconomic data has been a concern (Young 2003; Rawski and Xiao 2001; Holz 2004). For example, Holz (2006) and Chow (2006) debated on the various measurement problems in estimating the physical capital stock series. After taking into account the various additional estimations and assumptions, such as scrap rate, depreciation rate of the same capital equipment at different years, Holz (2006) concluded that the estimation of China's physical capital stock based on different assumptions do not vary much. The fact is that various capital stock series can be used as estimates to represent an acceptable scenario for empirical time series analysis.[1] Chow and Li (2002) rightly argued that China's macroeconomic data collection system is constantly improving, and believed that discrete statistical differences may cancel out each other in a trend analysis.[2]

Studies on TFP often assumed optimality in production capacity. However, the output-oriented stochastic frontier production approach argues that, with given sets of factor inputs and due to possible technical inefficiency, there can be deviations between actual and optimal output. In the context of the frontier production analysis, it is shown that productivity change or the growth of TFP is a composition of technical progress, technical efficiency change and scale of economy (Kumbhakar and Lovell 2000). Theoretically, technical progress refers to an outward shift of the economy's entire production frontier due probably to a greater use of technology and innovation and attained a larger production capacity. Technical efficiency change in an economy refers to an overall movement from a position within the production frontier towards the production frontier. The scale of economy component incorporates inputs elasticity when there were changes in the input level. The inputs elasticity provides a measure of the returns to scale. Under constant returns to scale input growth or contraction makes no contribution to productivity change.

The production frontier analysis has been used in studies on the China economy. Some studies related to economic sectors and used either enterprise or regional data (Huang and Kalirajan 1998; Kalirajan and Zhao 1997; Brummer *et al* 2006; Hu and McAleer 2005; Dong and Putterman 1997; Tong 1999; Kalirajan *et al* 1996; Wu 1995, 2000 and He and Chen 2004). Others, Fu (2005), for example, looked at the technical progress and growth of the export sector, while Wu (2003) used unelaborated investment data, a constant return assumption and an assumed rate of depreciation. These studies focus on either one or two components of productivity change; either technology change or scale of economy, or both are overlooked.

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[1] Recent studies (e.g. OECD 2001) argue that the more relevant contribution of a capital asset is the flow of capital services provided by the asset.

[2] While it is believed that China's GDP data are over-estimated, recent reports showed that due to the increase in the informal sector, China's GDP has been under-estimated and was revised upwards by US$300 billion in December 2005 (*South China Morning Post*, December 13 and 21, 2005 and January 13, 2006).

This paper expands the work by Liu and Li (2006) and Li (2003, 2007) and aims to examine the three components of the productivity change (technical progress, technical efficiency change and scale of economy) for China's thirty provinces grouped into four geographical and economic regions. We apply the maximum likelihood estimation (MLE) to an augmented logarithmic production function that incorporates a human capital variable.

The South region composes of nine southern provinces, commonly known as the Pearl River Delta provinces of Fujian, Guangdong, Guangxi, Hainan, Jiangxi, Hunan, Sichuan, Guizhou and Yunnan. The East region consists of twelve provinces, including mainly provinces in the Yellow River and Yangtze River Delta regions of Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Shandong, Anhui, Henan, Hubei, Shanxi and Gansu. The West region refers to the remote provinces of Mongolia, Tibet, Shaanxi, Qinghai, Ningxia, and Xinjiang. The remaining three provinces in North East region are Jilin, Heilongjiang and Liaoning, which consist of the traditional state-owned heavy industries. These four sub-regions in China are chosen to reflect the geographical strength and economic growth concentration.

Section 2 elaborates on the growth experience in post-reform China, giving various sources of data used in the empirical analysis. Section 3 discusses the methodology and empirical model, while section 4 presents the empirical results, and section 5 concludes the study.

2. China's Post-reform Economic Performance

The data for China's thirty provinces used in this paper comes mainly from the latest issue of the *Statistical Yearbook of China*, the *Comprehensive Statistical Data and Materials in 50 Years of New China* (1999), and the two Chinese censuses of 1990 and 2000. Figure 1 shows China's national and regional real GDP for the two decades of 1984 – 2004. The national real GDP has increased tremendously, giving an annual average real GDP growth rate of 9.8 percent in the two decades. China experienced a double or close to double digit real GDP growth rate for the period of 1992 - 2004. The twelve provinces in the East region experienced the highest average real GDP, and its growth has accelerated since 1992. Although the real GDP growth rate of the six provinces in the West region remained high, they experienced the lowest real GDP, and a widening real GDP gap between provinces in the East and West regions. The real GDP in the South and North East regions is close to the national average.

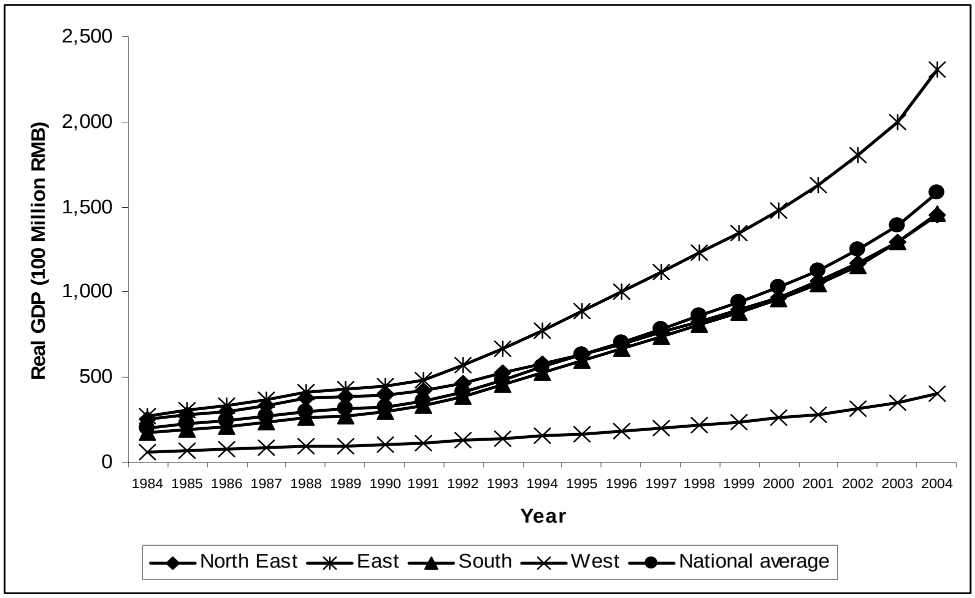

Figure 1 China's national and regional real GDP.

The estimation on the production function requires an indicator for the physical capital stock, which can often be approximated from investment figures (Chow and Li 2002; Young 2003; Wu 2000). We followed the methodology and updated the capital stock used in Chow and Li (2002), Li (2003) and Liu and Li (2006) to 2004. Figure 2 shows the average national and regional physical capital stock series for the sample period. The large average physical stock in the three provinces in the North East region has been overtaken by provinces in the East region in 2004. Despite the large export in light manufacturing, provinces in the South region has a lower than national average capital stock, while provinces in the West region have the lowest level of physical capital stock.

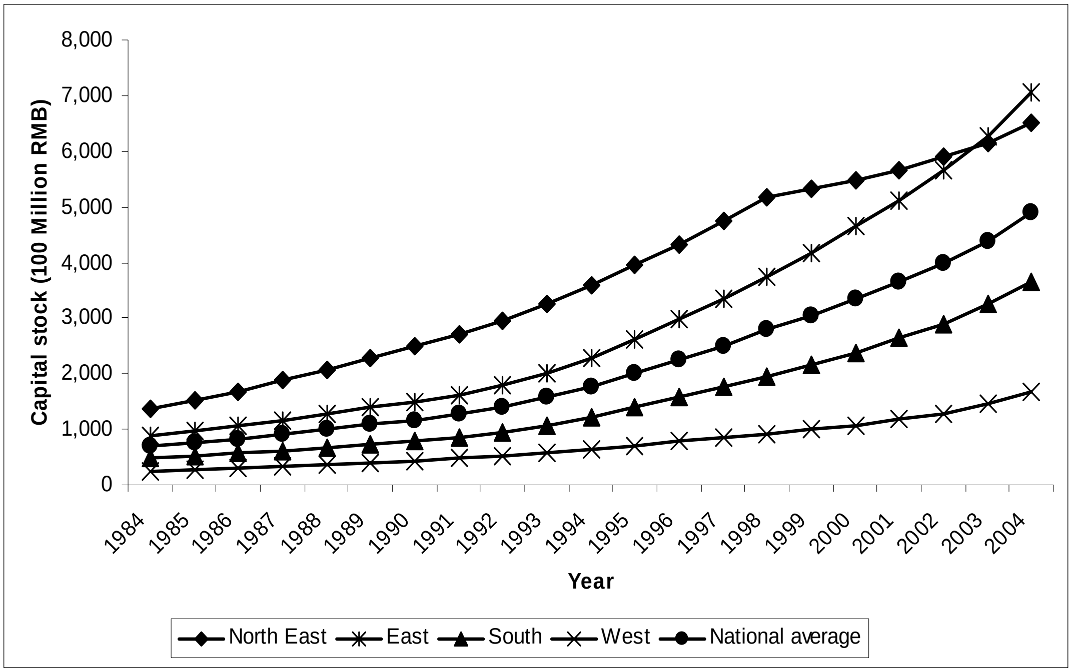

Figure 2 China's regional physical capital stock.

Human capital is generally related to the level of education, though empirically, a number of indicators are used as proxy for human capital (Barro and Lee 1993, 1996 and 2001; Benhabib and Spiegel 2005; Gemmell 1996).[3] Barro and Lee (2001) and Howitt (2005) maintained that life expectancy can impact on economic development via human capital-adjusted mortality rate. An increase in life expectancy would lead to an increase in human capital accumulation.

Scholars made various assumptions and proxies in constructing China's human capital stock (Young 2003; Wang and Yao 2003). Liu and Li (2006, Table 2 and Appendix B) and Li (2007) discussed China's post-reform education performance and constructed China's human capital stock using a perpetual inventory approach (Barro and Lee 1993, 1996, 2001). The initial human capital is derived from using the data in the two Population Censuses of 1990 and 2000. The annual graduates of the six schooling levels (Higher Education with 14.5 years, Specialized Secondary, Vocational Secondary and Senior Secondary with 11 years, Junior Secondary with 8 years and Primary Education

[3] These indicators include (1) total years of schooling derived from educational enrolment ratios; (2) international test scores; and (3) numbers of workers pass through primary, secondary and tertiary education.

with 5 years) and the total numbers of persons that have attained various schooling levels within the age 15 - 64 years in 1990 are used as the benchmark. Data on the annual graduates in each schooling level are adjusted by the mortality rate and inter-provincial migration figures. Due to a change in the classification on the education level of graduates after 2000, we can only extend the data for human capital stock in Liu and Li (2006, Appendix B) to 2000.[4]

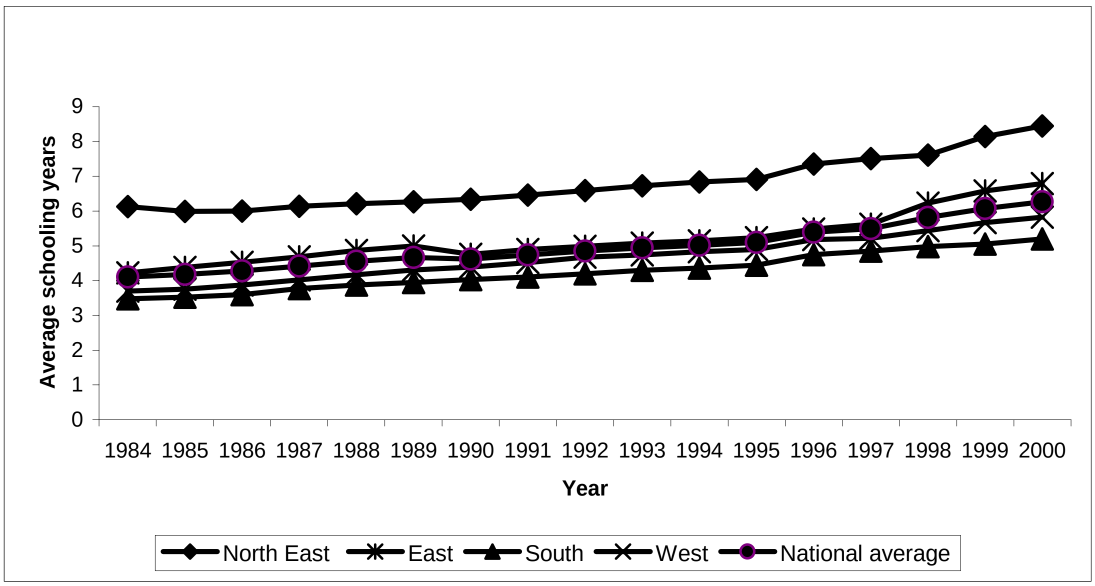

Figure 3 China's human capital per capita.

Figure 3 shows China's human capital stock measured in term of the average schooling years. The number of average schooling years has improved, with an national average of 4 years in 1984 increased to over 5 years in 2000.[5] Provinces in the North East and East regions showed a higher average schooling years than the national average, due probably to the demand by the traditional heavy industries, while provinces in the West and South regions showed a lower level of human capital.

[4] The statistics on the number of graduates at Specialized Secondary and Vocational Secondary education levels are not available since 2004.

[5] China's average schooling years derived for 1985, 1990, 1995 and 2000 are 4.17, 4.62, 5.10 and 6.27 years, respectively. Based on enrolment ratios for the total population aged 25 and above, Barro and Lee's (2001) estimates are 4.15, 5.23, 5.48 and 5.74 years, respectively.

3. Methodology

We start with a single output and multiple-input Cobb-Douglas production function for the i^{th} province as:

$$Y_i = AK_i^{\alpha} L_i^{\beta}, \tag{1}$$

where Y is the aggregate output, and the two inputs are physical capital, *K*, and labor, *L*, while *A* is the Hicks-neutral technology index. In this simple production function, human capital has an impact on production through direct and indirect channels (Barro and Sala-i-Martin 1999; Benhabib and Spiegel 2005; Howitt 2005; Vandenbussche *et al* 2006). Firstly, the level of human capital that embodied in the labor force could have a direct influence on aggregate production. Secondly, the level of human capital itself could facilitate technological innovation, imitation and adoption, and could indirectly impact on the aggregate production via the Hicks-neutral technology index in Equation (1).

A stochastic frontier production function is used to incorporate possible technical inefficiency in the production function of different provinces (Aigner *et al* 1977; Battese and Coelli 1988 and 1992; Greene 2005). Taking the logarithm transformation of Equation (1), the stochastic frontier production function for the panel data becomes:

$$y_{it} = a + bx_{it} + v_{it} - u_{it}, \tag{2}$$

where i =1, …N, and t =1, …T. y_{it} denotes the logarithm of output for i^{th} province at time t and x represents a vector of logarithms of production inputs such as physical capital and labor. The random error v_{it} is symmetric and normally distributed with $v_{it} \sim N(0, \sigma_v^2)$ and u_{it} is a non-negative truncated normal random error with the probability distribution of $N(\mu, \sigma_u^2)$, where μ is the mode of the normal distribution. The non-negative property of the random error u_{it} is used to measure technical inefficiency. Technical inefficiency is interpreted as the percentage deviation of observed performance, y_{it}, from the individual province's own best-practice frontier performance,

$y_{it}^* = a + bx_{it} + v_{it}$. Namely:

$$u_{it} = y_{it}^* - y_{it}. \qquad (3)$$

Technical inefficiency can either be time variant (u_{it}) or time invariant (u_i). In the case of time variant technical inefficiency, u_{it} can be expressed as a monotonic 'decay' function as (Battese and Coelli 1992):

$$u_{it} = \eta_t u_i, \qquad (4)$$

where $\eta_t = \exp[-\eta(t-T)]$, and η is an unknown scalar parameter. u_{it} can either be increasing (if $\eta < 0$), decreasing (if $\eta > 0$) or remained constant (if $\eta = 0$).

The maximum likelihood method is generally used to estimate the parameters in a stochastic frontier production (Battese and Coelli 1988, 1992; Kumbhakar and Lovell 2000). The minimum-mean-square-error predictor of the technical efficiency of the i^{th} province at the t^{th} time period is shown as (Battese and Coelli 1992; Kumbhakar and Lovell 2000; Coelli 1996; Battese and Corra 1977)[6]:

$$TE_{it} = E(\exp\{-u_{it}\} | \varepsilon_{it}), \qquad (5)$$

where $\varepsilon_{it} = v_{it} - u_{it}$.

To capture the indirect effects of the human capital stock on production, we follow Hall and Jones (1999) and Bils and Klenow (2000) by augmenting the logarithmic production function with the index of human capital stock per working population, *H*. In addition, by allowing variations in output and substitution elasticity with the levels of factor inputs, a production function with a second-order transcendental logarithmic (translog) form is:

[6] The detailed steps on the derivation of technical efficiency are provided in Battese and Coelli (1992, Appendix Equations A.1 - A.11).

$$\ln Y_{it} = \alpha + \beta_K \ln K_{it} + \beta_L \ln L_{it} + \beta_{KK} (\ln K_{it})^2 + \beta_{LL} (\ln L_{it})^2 + \beta_{KL} \ln K_{it} \ln L_{it}$$
$$+ \phi_H H_{it} + \sum \delta_{Tt} DT_t + \sum_r \delta_{Rr} DR_r + v_{it} - u_{it} , \quad (6)$$

where $\ln Y_{it}$ is the log of real GDP; $\ln K_{it}$ is the log of physical capital stock; $\ln L_{it}$ is the log of total employed persons; H_{it} is the human capital variable expressed in average schooling years;[7] DT_t is the dummy variable for the time trend to capture technology changes; DR_r is dummy variable for the different regions that will capture region-specific effects. The parameter δ_{Tt} can be used to measure technical level over time. The technology progression or the rate of change in technical level is $\delta_{Tt} - \delta_{Tt-1}$. Appendix Table A1 gives the statistical summary of main variables and Appendix Table A2 shows the result of the partial correlations matrix.

From Equation (6), the output elasticity for physical capital, labor, and human capital for province *i* and time *t*, which are denoted as θ_{Kit}, θ_{Lit}, and θ_{Hit}, respectively, can be derived as follows:

$$\theta_{Kit} = \beta_K + 2\beta_{KK} \ln K_{it} + \beta_{KL} \ln L_{it} , \quad (7)$$

$$\theta_{Lit} = \beta_L + 2\beta_{LL} \ln L_{it} + \beta_{KL} \ln K_{it} , \quad (8)$$

$$\theta_{Hit} = \phi_H H_{it} . \quad (9)$$

The return of scale is measured as $\theta_{it} = \theta_{Kit} + \theta_{Lit} + \theta_{Hit}$.[8]

In this paper, we apply Equation (6) to the data from China economy and derive the measures of productivity change and its sources. The productivity change or the total

[7] To control for the possible endogenerity of human capital, Liu and Li (2006) applied the two lags of human capital as instruments. Due to the complicity of the stochastic frontier model, this paper compromises the possible endogenerity of human capital, and focuses on output elasticity of the respective input variables and technical efficiency. If endogenerity is serious, the estimated coefficients will be biased and the conclusion from this paper may be conservative.

[8] For the basic Cobb-Douglas production function without the human capital input, the marginal effects of the respective factor inputs are equal to its respective estimated coefficients, and the return to scale is constant.

factor productivity (TFP) growth is decomposed into three components: (i) a shift in the production frontier or technology progress; (ii) change in technical efficiency; and (iii) the scale of economy (Kumbhakar and Lovell 2000: 284). This decomposition is shown as follows:

$$T\dot{F}P_{it} = \Delta\delta_{Tt} + \Delta TE_{it} + Scale_{it}\,, \tag{10}$$

where $Scale_{it} = (\theta_{it} - 1)\left\{(\theta_K \dot{K}_{it} + \theta_L \dot{L}_{it} + \theta_H \dot{H}_{it})\right\}/\theta_{it}$ is a measure of scale of economy, which takes into account both the inputs elasticity and the change in the level of the factor inputs. With the estimated results from Equation (6), the estimated coefficient for δ_{Tt} gives the estimates of the technology change; Equation (5) is used to derive the estimates of technology efficiency; Equations (7) – (9) are used for the estimates of scale of economy.

4. Empirical results

Table 1 reports maximum likelihood estimates of the stochastic frontier production for a panel of thirty provinces of China for the period of 1985-2000, with a total of 470 observations. The dependent variable is log real GDP. Columns (1) and (2) show the results without regional dummy variables, while columns (3) and (4) show the results with regional dummy variables. The difference between columns (1) and (2) and that between columns (3) and (4) is the use of the functional form. Columns (1) and (3) contain the results from the basic function of the production model, while columns (2) and (4) show the results from the translog specification of the production function.

The last three rows in Table 1 show the three sets of model specification tests. The first set contains the likelihood ratio tests for the joint effects of regional dummy variables. The statistics shown in columns (3) and (4) are statistically insignificant. Therefore, the regional dummy variables can be removed from the model. The second set contains the likelihood test for the joint effects of technology change. All statistics in this row show that the technology progress over time is significant. The third set contains the likelihood ratio tests for the joint effects of quadratic and interaction terms in the translog specifications. The results in columns (2) and (4) show these tests are statistically significant. In sum, the translog specification function without regional dummy variables shown in column (2) represents a preferred model for further analysis.

The estimates in column (2) of Table 1 show that the positive effects of physical capital are clearly predominant in the production functions. The effects of human capital on provincial GDP are also positive and statistically significant. The estimated technical inefficiency parameter, η, is negative and statistically significant, which indicates that the overall inefficiency is increasing over time. On the contrary, the estimates show that there is technical progress over the observed period, as the coefficients (δ_t) of the time trend are positive (results are not reported here), and their joint effects are statistically significant.

Based on the translog production function estimates shown in column (2) of Table 1, we use Equations (5), (7) – (10) to derive the following measures: the output elasticity with respect to factor inputs, return to scale (θ), index for the scale of economy (Scale), rate of technical progress ($\Delta\delta_{Tt}$), changes in technical efficiency (ΔTE) and total factor productivity growth ($T\dot{F}P$). Because the translog specification is used, the performance of these measures varies depending on provinces and years. The average of these measures on different provinces for different years is shown in Table 2. The overall means of these measures are summarized in the second last row and the means calculated from the basic production function (BF Mean), given by the estimates in column (1) of Table 1, are shown in the last row for comparison.

Table 2 shows that China's physical capital input gives the largest output elasticity with values more than 0.67. Labor has output elasticity that ranges between 0.251 and 0.285; human capital has output elasticity that ranges between 0.113 and 0.169. The total return to scale from these three inputs is between 1.045 and 1.15 with an increasing trend.

For the three sources of the TFP growth, the contribution from technical efficiency is negative in all years and the major contributors to the TFP growth are the scale of economy (Scale) and technical progress ($\Delta\delta_{Tt}$). The scale of economy has increased significantly from 0.003 in 1986 to 0.012 in 2000. In spite of this significant increase over the sample period, its estimates are still about one-half to one-third of the estimates of technical progress for the last three years in our sample. The estimates of technical progress are all positive, except in 1989, and the estimates reached the highest level between 1992 and 1994 with values of 0.069, 0.058 and 0.050.

Table 1 Maximum likelihood estimates of the stochastic frontier production (1985-2000)

	(1)	(2)	(3)	(4)
lnK	0.674 ***	0.726 ***	0.671 ***	0.733 ***
	(0.030)	(0.116)	(0.029)	(0.130)
lnL	0.229 ***	-0.425 **	0.238 ***	-0.459 **
	(0.035)	(0.183)	(0.037)	(0.193)
lnK*lnK	-	0.004	-	0.004
	-	(0.007)	-	(0.008)
lnL*lnL	-	-0.089 ***	-	-0.097 ***
	-	(0.020)	-	(0.021)
lnK*lnL	-	0.047 **	-	0.050 **
	-	(0.023)	-	(0.024)
H	0.017 **	0.027 **	0.016 **	0.028 **
	(0.007)	(0.012)	(0.007)	(0.013)
Northeast region	-	-	-0.011	-0.118
			(0.090)	(0.092)
East region	-	-	-0.071	-0.084
			(0.076)	(0.076)
South region	-	-	-0.050	-0.099
			(0.074)	(0.077)
μ	0.433 ***	0.419 ***	0.379 *	0.390 **
	(0.166)	(0.133)	(0.218)	(0.158)
η	-0.026 ***	-0.026 ***	-0.025 ***	-0.025 ***
	(0.003)	(0.004)	(0.003)	(0.004)
σ_u^2	0.199	0.120	0.239	0.132
	(0.097)	(0.057)	(0.132)	(0.069)
σ_v^2	0.003	0.003	0.003	0.003
	(0.0002)	(0.0002)	(0.0002)	(0.0002)
Log likelihood	641.794	653.108	642.395	654.284
Log-Likelihood Ratio Tests (χ^2):				
$\delta_{Rr} = 0, \textit{for all } r$	-	-	1.20	2.14
$\delta_{Tt} = 0, \textit{for all } t$	242.09 ***	131.24 ***	209.45 ***	117.94 ***
$\beta_{KK,LL,LK} = 0$	-	23.46 ***	-	24.67 ***

The overall mean of the TFP growth is 0.032, which is close to the other earlier studies (Borenstein and Ostry 1996; Chow and Li 2002; Li 2003). Instead of measuring the TFP from the residual of the production function, we derive the TFP growth from the three components of its source, with 0.007 from the scale of economy, 0.031 from technical change, and -0.006 from the change in technical efficiency. These findings show that although factor accumulation may lead to the TFP growth through the increase in scale of economy, the most important factor for China's growth in TFP is technical change. In addition, the adverse effect from the change in technical efficiency reduced the potential growth in the TFP.

The last two rows in Table 2 show that the mean of return to scale calculated from the translog specification is 1.084,[9] which is slightly large than the return to scale (0.920) of the basic production form. However, this small difference gives opposite signs in the scale of economy; the mean values from the translog specification gives a positive scale of economy with a value of 0.007, whilst the scale value calculated from estimations of the basic form suggest a presence of diseconomy of scale (-0.006). Due to the difference in the scale of economy, the mean growth of TFP for the translog specification (0.032) is larger than that for the basic production specification (0.022). This comparison from the last two rows in Table 2 indicates that the conclusion about the growth TFP depends on the model specifications of the production function.

Estimates in column (2) of Table 1 are fitted into Equations (5) and (7) – (9) and averaged over different years to derive the individual provincial technical efficiency and output elasticities for the three inputs. These measures are grouped into four different regions, as shown in Table 3. For the measure of the level of technical efficiency, the rankings are firstly the East region, followed by the South region, the Northeast region and the West region. This implies that the high economic growth in the East region and South region is accompanied by the greater technical efficiency. Figure 4 reports the regional average efficiency levels in the sample period, and the trends show a slight decline in all four regions.

Table 3 also shows that the output elasticity varies among four regions. The output elasticities from physical capital are similar for Northeast, East, and South regions with values that range between 0.6975 and 0.7065, and that the West is the lowest with 0.6255; the output elasticity from labor in the West region is comparatively larger than other

[9] The joint-effect tests for θ_K is $\chi^2(3) = 694.78$ and for θ_L is $\chi^2(3) = 77.40$, and the tests are statistically significant.

regions; the output elasticity from human capital for Northeast (0.1848) is the highest and South is the lowest (0.1138). Because of the large difference in output elasticity from labor, it gives the West region the largest scale of economy and the South region the lowest scale of economy. Figure 5 shows that the scale of economy for each region has an increasing trend.

Table 2 Maximum likelihood estimates:
input elasticities, scale, technical progress, technical efficiency and $T\dot{F}P$

Year	θ_K	θ_L	θ_H	θ	Scale	$\Delta\delta_{Tt}$	ΔTE	$T\dot{F}P$
1985	0.675	0.254	0.113	1.042	-	-	-	-
1986	0.677	0.253	0.116	1.046	0.003	0.010	-0.005	0.008
1987	0.679	0.253	0.119	1.051	0.004	0.033	-0.008	0.029
1988	0.681	0.253	0.123	1.057	0.005	0.040	-0.006	0.039
1989	0.683	0.254	0.126	1.062	0.004	-0.013	-0.006	-0.014
1990	0.684	0.253	0.125	1.062	0.004	0.004	-0.015	-0.016
1991	0.686	0.251	0.128	1.066	0.005	0.027	-0.006	0.026
1992	0.688	0.253	0.131	1.072	0.006	0.069	-0.006	0.069
1993	0.690	0.254	0.133	1.078	0.007	0.058	-0.006	0.059
1994	0.691	0.257	0.135	1.084	0.007	0.050	-0.006	0.051
1995	0.693	0.260	0.138	1.091	0.008	0.038	-0.006	0.039
1996	0.695	0.263	0.146	1.103	0.011	0.033	-0.006	0.038
1997	0.696	0.266	0.148	1.110	0.009	0.034	-0.007	0.036
1998	0.697	0.270	0.157	1.124	0.011	0.017	0.003	0.032
1999	0.696	0.281	0.164	1.141	0.012	0.030	-0.007	0.036
2000	0.697	0.285	0.169	1.150	0.012	0.032	-0.007	0.037
Mean	0.688	0.260	0.136	1.084	0.007	0.031	-0.006	0.032
BF Mean	0.674	0.229	0.017	0.920	-0.006	0.035	-0.007	0.022

Notes: The indicators are for the whole China economy. BF Mean = mean values calculated of the basic production function estimates shown in column (1) of Table 1.

One can conclude from Table 3 and Figures 4 and 5 that the high economic growth in the East and South regions are mainly related to technical efficiency. The low output elasticity from labor and scale of economy in these two regions did not impede the economic growth. In general, it is advisable for China to go beyond mere factor accumulation but concentrate on policies that utilize production resources more efficiently, in particularly in Northeast and West regions.

Table 3 Technology efficiency, input elasticity, return to scale, and scale effect

	TE	θ_K	θ_L	θ_H	θ	Scale
National Average	0.6866	0.6880	0.2600	0.1357	1.0836	0.0073
Northeast	0.5716	0.6975	0.2742	0.1848	1.1565	0.0130
East	0.7564	0.7065	0.2274	0.1444	1.0783	0.0078
South	0.7360	0.7017	0.1906	0.1138	1.0061	0.0008
West	0.5153	0.6255	0.4223	0.1256	1.1734	0.0137

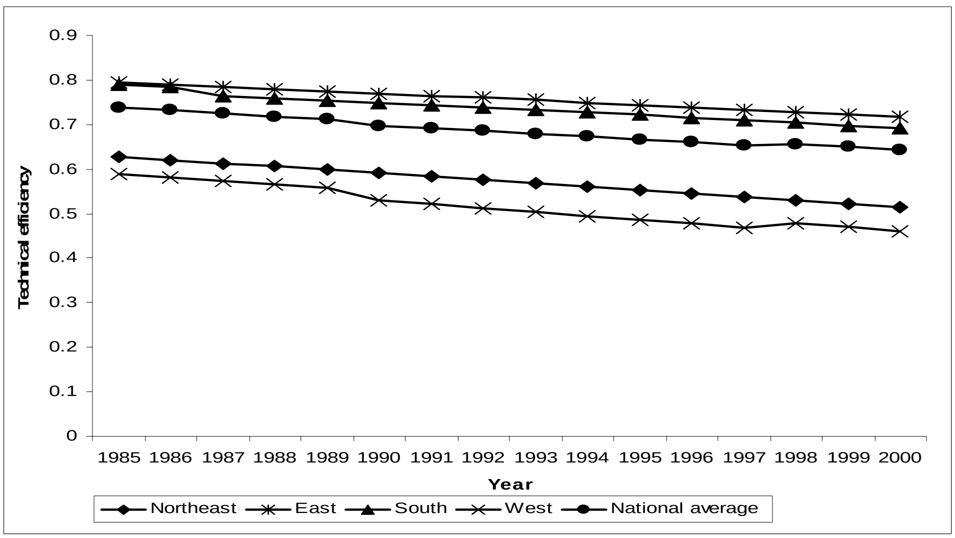

Figure 4 Average technical efficiency level by regions, 1985-2000

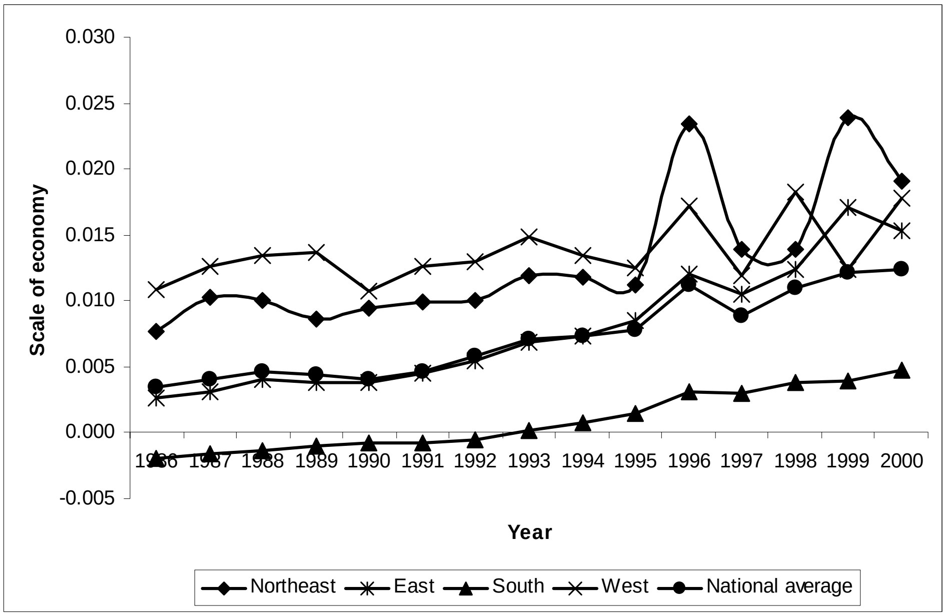

Figure 5 The scale of economy by regions, 1986-2000

5. Conclusion

This paper has worked out the physical and human capital stocks using the inventory method for the thirty provinces of China for the period 1984-2004. The average schooling year is used as the proxy for the human capital stock, where the numbers of graduates, provincial immigration and mortality at various education levels are taken into account. Due to the change in the classification of graduates, the human capital stock series is constructed to 2000. We have updated and extended the TFP analysis in Chow and Li (2002), Li (2003) and Liu and Li (2006). Various improvements in this paper included the use of a human capital variable and other original data, and the thirty provinces are grouped into four key regions.

We estimate the stochastic frontier translog production function and analyze the productivity change of the individual provinces by using the maximum-likelihood estimation method. Our empirical results show that the three factor inputs (physical capital, labor and human capital) are important for output performance. Although Young (2000, 2003) argues that China's economic development came largely from the increase in physical capital, other studies (Galor and Moav 2003; Goldin and Katz 1998, 1999 and 2001) argue that in the early stage of economic development, such as that of China in the post-reform years, physical capital is usually the dominant input factor. The role of human capital will become significant in the more mature stage of economic development. Our results are consistent with earlier studies and show clearly that the physical capital is the most important factor to China's post-reform economic growth, and it is important for China to upgrade its human capital for sustainable economic development.

When the three sources of the growth of TFP are considered, we found that the major contributor to the TFP growth is technology progress, with the exception in 1989 and 1990. The scale of economy accounts for about one-third of the TFP growth during the last three years in our sample period and the negative change in technical efficiency reduced the potential growth in TFP. While the levels of technical efficiency appeared to be slightly decreasing over the period, the South and East regions in China have comparative higher levels of technical efficiency than the Northeast and West regions. With lower technical efficiency and high output elasticity for labor, the Northeast and West regions are characterized by higher return to scale and scale of economy.

The empirical results do bring forward several policy implications on the sustainability of the post-reform China economy. It is necessary for China to promote more productive investment, in particular those embodied with comparative higher technological vintages. Policies should be geared to improve technical efficiency and utilize resources effectively.

Furthermore, the important variable of human capital is still scarce in China, and it will take a relatively longer time for individuals to be educated and trained. Thus, continuous investment on education and training is necessary. Mobility of human capital can facilitate knowledge spillovers across different provinces in China, and encouraging international flows of talents might also be necessary. It will be interesting for future analysis, for example, to consider the efficiency level among industries in different regions in the post-reform China.

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Appendix

Table A1 Summary statistics of the main variables, 1985-2000

	Obs.	Mean	Std. Dev.	Min	Max
lnGDP	480	5.790	1.092	2.579	8.089
lnL	480	-2.000	0.951	-4.550	-0.585
lnK	480	6.999	0.978	4.482	9.408
H (average schooling years)	470	5.028	1.586	0.901	10.725

Table A2 Correlation of the main variables, 1985-2000

	lnGDP	lnL	lnK	H
lnGDP	1.000	-	-	-
lnL	0.805 (0.000)	1.000	-	-
lnK	0.948 (0.000)	0.650 (0.000)	1.000	-
H	0.493 (0.000)	0.044 (0.340)	0.609 (0.000)	1.000